

Nitrogen and Tillage Effects on Wheat Leaf Spot Diseases in the Northern Great Plains

J. M. Krupinsky,* A. D. Halvorson, D. L. Tanaka, and S. D. Merrill

ABSTRACT

There is a need for management practices in cropping systems that can reduce the impact of plant diseases. Leaf spot diseases on wheat (*Triticum aestivum* L.) were evaluated for 11 yr to determine the influence of tillage, N fertilization, and cultivar on disease severity in a long-term cropping system project, which included two cropping systems [spring wheat (SWF)–fallow and annual cropping [spring wheat (SWA)–winter wheat (WWA)–sunflower (*Helianthus annuus* L.)]]. The major leaf spot diseases were tan spot and *Stagonospora nodorum* blotch. In low precipitation years, the impacts of management practices on leaf spot disease severity were minimal. No-till (NT) did not consistently increase the severity of leaf spot diseases. During the drier years, NT had the advantage of conserving soil water while not increasing the risk to leaf spot diseases. When N treatments influenced leaf spot disease severity, higher levels of disease severity were associated with the low-N fertilizer treatment compared with higher levels of N fertilization. When a tillage \times N treatment interaction was significant, disease severity was higher with NT at the low N treatment, but at the high N treatment the differences among tillage treatments were greatly reduced or eliminated. This indicates an advantage of using adequate N fertilizer especially with NT under our environmental conditions. When differences in leaf spot diseases for cultivars were evident, Roughrider winter wheat had higher levels of disease severity compared with Norstar; however, the differences between the spring wheat cultivars Butte86 and Stoa were not consistent for both cropping systems. Producers should integrate a combination of management practices to develop a consistent long-term strategy for disease management suited to their production system and location.

ACCORDING TO THE 2004 National Crop Residue Management Survey, adoption of NT has increased in the USA from 42 million ha (6%) in 1990 to >154 million ha (23%) in 2004 (Conservation Technology Information Center, 2006). No-till systems, which allow crops to be seeded with minimal soil and residue disturbance, leave crop residue on the soil surface and eliminate tillage trips, limiting inputs of labor, fuel, and machinery. The retention of crop residues on the soil surface protects soil and land resources from erosion, conserves soil water, maintains soil quality, and influences the soil surface environment. Crop residues left on the soil surface

result in increased soil organic C (Liebig et al., 2005), improved soil physical properties (Arshad et al., 1999; Pikul and Aase, 1995), and enhanced microbial activity and biomass (Liebig et al., 2006). Such changes in near-surface soil condition improve the functioning of cropping systems through increased precipitation-use efficiency and water storage (Aase and Reitz, 1989; Deibert et al., 1986; Peterson et al., 1996; Tanaka and Anderson, 1997), reduced soil erosion (Merrill et al., 1999), and improved nutrient conservation (Follett and Schimel, 1989). Collectively, improvements in soil condition through the retention of crop residues on the soil surface increase the resilience of Great Plains cropping systems to droughts, wet periods, intense precipitation events, and extreme temperatures, all of which are common to the region (Peterson, 1996).

Wheat is a major crop in the northern Great Plains region. Leaf spot diseases on wheat are caused by several fungal pathogens. The common leaf spot diseases are tan spot {caused by *Pyrenophora tritici-repentis* [Died.] Drechs. (anamorph, *Drechslera tritici-repentis* [Died.] Shoemaker)} and *Stagonospora nodorum* blotch {caused by *Phaeosphaeria nodorum* [E. Müller] Hedjaroude (anamorph, *Stagonospora nodorum* [Berk.] Cast. et Germ.)}. Other leaf spot diseases present include spot blotch, caused by *Cochliobolus sativus* [Ito and Kurib.] Drechs. ex Dastur [anamorph, *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem.]; *Stagonospora avenae* blotch, caused by *Phaeosphaeria avenaria* (G. F. Weber) O. Eriksson f. sp. *triticea* T. Johnson (anamorph, *Stagonospora avenae* Bissett f. sp. *triticea* T. Johnson); and *Septoria* leaf blotch, caused by *Mycosphaerella graminicola* (Fuckel) J. Schrt. in Cohn (anamorph, *Septoria tritici* Roberge in Desmaz.) (Fernandez et al., 1998a, 1998b; Gilbert and Woods, 2001; Krupinsky et al., 2004; Krupinsky and Tanaka, 2001; McMullen, 2003; Wang et al., 2002).

Increased amounts of crop residue on the soil surface with conservation tillage may influence plant diseases (Conway, 1996; Jardine et al., 2000; Krupinsky et al., 2002; McMullen and Lamey, 1994; Rothrock, 1992; and Watkins and Boosalis, 1994). Conservation tillage practices can lessen some soil-borne plant diseases by increasing soil microbial activity and subsequently, the likelihood of competition among organisms in the soil, but understanding of the mechanisms involved is limited (Bailey and Lazarovits, 2003). In contrast, conservation tillage practices may favor some plant pathogens by lowering soil temperature, increasing soil moisture, and leaving the residue and soil undistributed (Bockus and Shroyer, 1998). Studies have shown that the interaction between diseases and residue is influenced by the soils,

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Abbreviations: CT, conventional till; MT, minimum till; NT, no-till; SWA, spring wheat in an annual cropping system; SWF, spring wheat in a spring wheat–fallow system; WWA, winter wheat in an annual cropping system.

region, or prevailing environment, and the biology of the disease organism (Krupinsky et al., 2002).

A combination of management practices, including the use of crop rotation, resistant cultivar, biocontrol, fungicide application, and proper fertilization, may be employed to minimize diseases in conservation tillage systems (Bockus, 1998; Jardine et al., 2000; Krupinsky et al., 2002, 2004; McMullen and Lamey, 1994; Turkington et al., 2003). At Guelph, ON, Canada, leaf spot diseases increased with NT when wheat followed wheat, and decreased when wheat followed other crops (Sutton and Vyn, 1990). At Mandan, ND, USA, when comparing crop sequences in a NT system, differences in leaf spot disease severity between the wheat-after-another crop treatments and the wheat-after-wheat treatment were more obvious with early season evaluations (Krupinsky et al., 2004, 2006). In the semiarid area of the western Canadian prairies, leaf spot severity was reported to be greater in wheat grown after fallow than in continuous wheat, with disease severity being similar for three tillage methods (Fernandez et al., 1998b). In Saskatchewan, crop rotation and tillage had less of an impact on disease severity than the annual environment (Bailey et al., 2000). At Mandan, when converting a grass-legume mixture back to cropland, the tillage treatment did not influence leaf spot diseases of winter wheat 1 yr, but during another year with higher precipitation, higher disease severities were associated with the NT treatment (Krupinsky and Tanaka, 2001). At Langdon, ND, USA, when comparing chisel tillage with moldboard plowing, higher foliar diseases were associated with chisel tillage early in the season, but the effects did not carry over to late-season disease levels (Stover et al., 1996). Increasing rates of N fertilizer may increase, decrease, or have no effect on disease severity of foliar septoria or stagonospora diseases, depending on the region or prevailing environment (Krupinsky, 1999).

Earlier reports concerning the same long-term cropping system project have indicated that producers in the northern Great Plains can produce spring wheat, winter wheat, and sunflower in annual cropping systems, particularly with NT or minimum till (MT) (Halvorson et al., 1999a, 1999b, 2000a). Overall, the annual cropping system generated higher profits than the spring wheat-fallow system, but the profits were more variable (DeVuyst and Halvorson, 2004). Considering that management practices influence the severity of plant diseases, the objective of this study was to determine the influence of tillage, N fertilization, and cultivar on the severity of leaf spot diseases on winter and spring wheat in this long-term project that included both annual cropping and spring wheat-fallow systems.

MATERIALS AND METHODS

A long-term cropping system project was conducted from 1984 through 1996 on a 25-ha site at the Area IV Soil Conservation Districts/USDA-Agricultural Research Service Research Farm near the Northern Great Plains Research Laboratory, southwest of Mandan. The predominant soil at the site is Temvik-Wilton silt loam (Fine-silty, mixed, superactive, frigid Typic and Pachic Haplustolls). The project included

spring wheat-fallow and annual (spring wheat-winter wheat-sunflower) cropping systems. The three tillage treatments were conventional till (CT, <30% surface residue coverage at seedling), MT (30–60% surface residue coverage), and NT (>60% surface residue coverage). More comprehensive surface residue coverage data for tillage treatments in the spring wheat-fallow system from 1988 through 1994 was reported by Merrill et al. (1999). Two winter wheat cultivars, Roughrider and Norstar, and two spring wheat cultivars, Stoa and Butte 86, were used throughout the study. Roughrider, Butte 86, and Stoa were considered to be moderately susceptible, and Norstar was considered to be moderately resistant to leaf spot diseases. Nitrogen treatments were 34, 67, and 101 kg N ha⁻¹ [30, 60, and 90 pounds N acre⁻¹] for the annual cropping system and 0, 22, and 45 kg N ha⁻¹ [0, 20, and 40 pounds N acre⁻¹] for the spring wheat-fallow system, because of the fallow contribution to N levels. Nitrogen was applied in early spring as a broadcast of NH₄NO₃, except no N was applied in 1991 and 1992 because of a buildup in residual soil N due to drought conditions and low yields in 1988 and 1989. Phosphorus fertilizer was applied broadcast at a rate of 40 kg P ha⁻¹ at the beginning of the study in 1983.

Each main block of the study was 137 by 73 m in size. Tillage plots (46 by 73 m) were orientated in a north-south direction, N plots (137 by 24 m) in an east-west direction across all tillage plots, and cultivars (23 by 73 m) in a north-south direction within tillage plots across all N plots. Experimental design was a strip-split-plot design, with tillage and N treatments stripped and cultivar as subplots, with three replications. Enough blocks were established to allow all phases of the cropping systems to be present each year (three spring wheat blocks and three fallow blocks for the spring wheat-fallow system; plus three spring wheat blocks, three winter wheat blocks, and three sunflower blocks for the annual cropping system = 15 main blocks). In 1989, the winter wheat plots for the CT and MT treatments were seeded to spring wheat because the winter wheat was winterkilled. Herbicide use was previously described (Black and Tanaka, 1997; Halvorson et al., 1999a, 1999b, 2000a, 2000b). In this semiarid region, precipitation averaged 41 cm (16 in) per year with an average of 30 cm (12 in) received during the growing season (April, May, June, July, and August; Fig. 1). Research results from this long-term project have been previously reported: crop production (Halvorson et al., 1999a, 1999b, 2000a, 2000b), weed growth (Anderson et al., 1998), soil properties (Black and Tanaka, 1997; Halvorson et al., 2001a, 2001b, 2002), crop root growth and water conservation (Merrill et al., 1996), soil erosion (Merrill et al., 1999), and economics (DeVuyst and Halvorson, 2004). A preliminary plant disease report was made (Krupinsky et al., 1998).

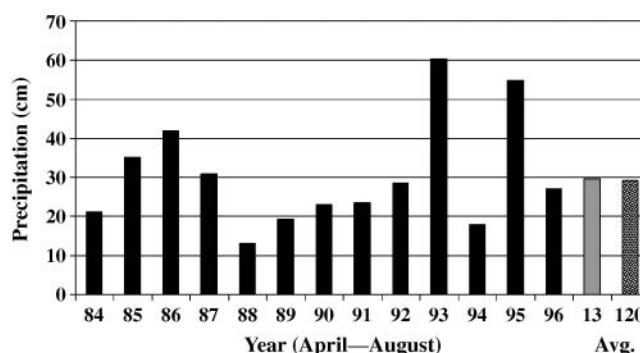


Fig. 1. Growing season precipitation from April through August, 1984 to 1996. Averages for 13 and 120 yr are included for comparison.

Leaf Spot Disease Severity

Three wheat crops (SWA, WWA, and SWF) were visually evaluated for severity of leaf spot diseases. The total percentage of necrosis and chlorosis on wheat leaves was used as an indicator of disease severity. Plots (18 plots per main block; three N \times two cultivars \times three tillage treatments) were rated several times each year when adequate disease symptoms were present. From each plot evaluated, 20 leaves of the same leaf position from plants at a similar stage of development were randomly collected. Leaves visually evaluated for leaf spot disease severity were the flagleaf (FL, the uppermost leaf), flagleaf-1 (FL-1, first leaf below the flagleaf), flagleaf 2 (FL-2), and flagleaf 3 (FL-3). The leaves rated most frequently were FL, FL-1, and FL-2. Growth stages ranged from boot through heading (10–10.5, Feekes scale [Large, 1954]) for the FL-2 evaluations, from heading through anthesis (10.5–10.5.4, Feekes scale) for the FL-1 evaluations, and from anthesis through milk/dough (10.5.1–11.2, Feekes scale) for the FL ratings. No visual evaluations for disease severity were done in 1988 because of the low level of disease symptoms related to drought conditions. No visual evaluations for disease severity were done on winter wheat in 1989 because of winter-kill and in 1992 because of water-stress symptoms and the low level of disease symptoms. Only the NT treatment was visually evaluated for SWA in 1992 because of water-stress symptoms and the low level of disease symptoms on the MT and CT treatments.

Leaf Spot Fungi Present

To identify the most common fungi present, naturally infected wheat leaves with leaf spot symptoms were collected from all plots during all years, including years when the level of disease symptoms was minimal and visual evaluations for disease severity were not practical. Wheat leaves from WWA (1577), SWA (1244), and SWF (1612) were processed for fungi present from 1987 through 1996. Leaves were pressed, allowed to dry, and stored in a refrigerator at 3–5°C until they were processed. One to six months after collection, leaf sections about 3 cm long were surface-sterilized for 3 min in a 1% sodium hypochlorite solution containing a surfactant (Tween 20, polyoxyethylenesorbitan monolaurate, Sigma Chemical Co., St. Louis, MO), rinsed in sterile distilled water, placed on water agar (18% agar) in plastic Petri dishes, and incubated under a 12-hr photoperiod (cool-white fluorescent tubes) at 20°C. After an incubation of six to 7 d, leaf sections were examined for fungi microscopically. Fungal spores were transferred from leaf tissue to a glass slide, stained with cotton blue or aniline blue, and microscopically identified with a compound Zeiss microscope illuminated with an Illuminator 100 (Carl Zeiss Inc., Thornwood, NY). The number of leaf sections infected with a particular fungus was used as an indicator of the relative importance of that fungus in causing leaf spot disease in a particular plot.

Common Root Rot Present

After 7 yr into the long-term project (1991, 1992, and 1993), subcrown internodes of spring wheat plants from each of the three tillage treatments were examined for the presence of common root rot, caused by *Cochliobolus sativus*, the same fungus that causes spot blotch on the leaves. Forty-two spring wheat plots (SWA and SWF) were sampled (about 50 plants per plot) in 1991 and 1992, and six plots in 1993. Spring wheat plants were dug, cleaned with a power sprayer, and the subcrown internodes were classified as clean, slight, moderate, and severe according to the procedures of Tinline et al. (1975).

Statistical Analyses

The arcsine-transformed total percentage of necrosis and chlorosis, used as an indicator of disease severity, was analyzed for each disease assessment using the GLM (general linear model) procedure (SAS v. 9.1, SAS Inst., Cary, NC). Statistical comparisons within each study were made with Student-Newman-Keuls' test (SAS). Statistical differences were evaluated at a probability level of $P \leq 0.05$.

RESULTS AND DISCUSSION

Leaf Spot Fungi Present

Several fungal pathogens were often present on wheat leaves processed. Overall, *P. tritici-repentis* was present on 76% (65% for WWA leaves, 73% for SWA, and 88% for SWF), *P. nodorum* on 73% (81% for WWA leaves, 62% for SWA, and 71% for SWF), and *C. sativus* on 13% of the leaves processed. *Phaeosphaeria avenaria* f. sp. *triticea* was only present on 4% of leaves processed overall but was identified on 16% of the wheat leaves processed (1994 through 1996) after the higher precipitation in 1993 (Fig. 1).

Using the number of leaf sections infected with a particular fungus as an indicator of the relative importance of fungal pathogens, *P. tritici-repentis* and *P. nodorum* were the major pathogens causing leaf spot diseases of wheat from 1987 to 1996. The presence of plant pathogens varied among years, ranging from 58 to 95% for *P. tritici-repentis* and from 37 to 91% for *P. nodorum* (Fig. 2). Even though disease severity was limited because of low precipitation levels during 1988 to 1992 (Fig. 1), disease incidence was still high, evidenced by the number of wheat leaves infected with plant pathogenic fungi. Higher precipitation in 1993 (Fig. 1) apparently influenced an increase in the identification of *P. nodorum* (Fig. 2), which carried over into 1994, a drier year. The increased isolation in 1993 is consistent with the disease cycle of *P. nodorum*, since asexual spores are dispersed with splashing water (Wiese, 1987). This buildup is similar to the increased isolation of *P. avenaria* f. sp. *triticea* after the higher precipitation in 1993.

Isolation frequencies are consistent with other reports from the region. *Pyrenophora tritici-repentis* and *P. nodorum* were reported as major disease components

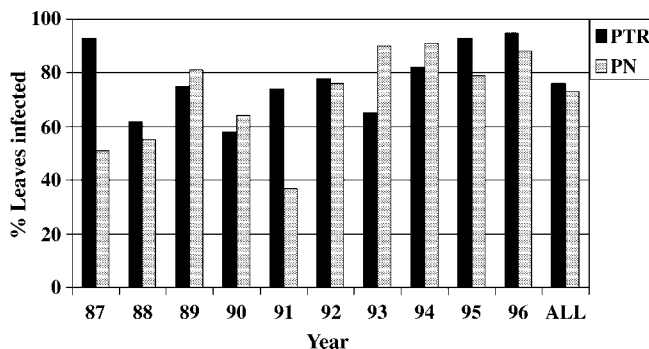


Fig. 2. The percentage of wheat leaves infected with *Pyrenophora tritici-repentis* (PTR, cause of tan spot), and *Phaeosphaeria nodorum* (PN, cause of Stagonospora nodorum blotch), major components of a leaf spot disease complex on wheat.

Table 1. Effect of N fertilization on leaf spot disease severity on spring wheat (SWA)[†] after sunflower, averaged across tillage and cultivar. The N effects summarized are the mean differences between the specified N level in contrast to the other two levels.

Year	Total no. of ratings	Statistical differences		Nitrogen		
		Significance at $P < 0.05$	No significant difference	34 kg ha ⁻¹	67 kg ha ⁻¹	101 kg ha ⁻¹
1996	6	6	0	H 6‡	H 1	–
1995	9	7	2	H 7§	–	–
1994	7	4	3	H 4	H 1	–
1993	2	2	0	H 2	–	–
1992	4	0	4	–	–	–
1991	3	0	3	–	–	–
1990	2	0	2	–	–	–
1989	2	0	2	–	–	–
1987	10	2	8	H 2	H 2	–
1986	6	2	4	H 2	–	–
Overall	51	23 (45%)	28 (55%)	23 (45%)	4 (8%)	–
1989–1992	11	0	11 (100%)	–	–	–
1986, 1987, and 1993–1996	40	23 (58%)	17 (43%)	23 (58%)	4 (10%)	–

[†] SWA was not evaluated in 1988 because of water-stress symptoms and the low level of disease symptoms. Only NT was evaluated in 1992 because of water-stress symptoms and the low level of disease symptoms associated with the conventional till and minimum till treatments.

‡ Disease severity for the 34 kg N ha⁻¹ treatment was higher than the 101 kg N ha⁻¹ treatment for all significant analyses and higher than the 67 kg N ha⁻¹ treatment for five of six significant analyses. In one analysis, disease severity for the 67 kg N ha⁻¹ treatment was higher than the 101 kg N ha⁻¹ treatment and similar to the 34 kg N ha⁻¹ treatment. H = significantly higher disease severity for a particular treatment, followed by number of analyses.

§ Disease severity for the 34 kg N ha⁻¹ treatment was higher than the other treatments for all significant analyses.

on winter wheat grown in 1996 and 1999 (Krupinsky and Tanaka, 2001) and spring wheat grown in 1999 and 2000 (Krupinsky et al., 2004). In the semiarid region of southern Saskatchewan, north and northwest of North Dakota, *P. tritici-repentis* and *P. nodorum* were most commonly isolated by Fernandez et al. (1998b). With higher precipitation levels in southern Manitoba, north and northeast of North Dakota, Gilbert and Woods (2001) commonly isolated *P. tritici-repentis*, *P. nodorum*, and *C. sativus*, as well as *M. graminicola*, which was rarely isolated in the present study. Other plant diseases such as powdery mildew (*Erysiphe graminis* DC. f. sp. *tritici* E. Marchal), stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Ericks. & E. Henn.), or leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici*) were present at very low levels or not evident in the present project.

Common Root Rot Present

Differences among management practices for the incidence of common root rot were not evident because common root rot on spring wheat was detected at low levels (overall, 89% of 2049 plants were rated

clean [no symptoms] and <1% severe). Thus, common root rot was considered to be a minor disease factor in this study.

Leaf Spot Disease Severity and Management Practices

Evaluations during this long-term cropping system project provided an opportunity to detect differences among management practices that may or may not have been evident in a short-term project. Overall, a wheat crop grown under different management practices was evaluated for leaf spot disease severity 162 times during 11 yr, from 1986 through 1996 (Tables 1–4). During the lower precipitation years from 1988 through 1992 (Fig. 1) it was difficult to detect differences in disease severity among management practices. For example, N fertilization treatments did not significantly impact disease severity for five continuous years (1988–1992) on the SWA crop (Table 1). Thus, lower precipitation levels impacted leaf spot disease severity making it difficult to distinguish among treatments. This agrees with the conclusion of Bailey et al. (2000) that the environment can

Table 2. Effect of N fertilization on leaf spot disease severity on winter wheat (WWA)[†] after spring wheat, averaged across tillage and cultivar. The N effects summarized are the mean differences between the specified N level in contrast to the other two levels.

Year	Total no. of ratings	Statistical differences		Nitrogen		
		Significance at $P < 0.05$	No significant difference	34 kg ha ⁻¹	67 kg ha ⁻¹	101 kg ha ⁻¹
1996	6	6	0	H 6‡	H 1	–
1995	7	6	1	H 6	H 5	–
1994	7	5	2	H 4	–	–
1993	3	0	3	–	–	–
1991	5	1	4	H 1	H 1	–
1990	3	0	3	–	–	–
1987	11	5	6	H 5	–	–
1986	8	5	3	H 5	–	–
Overall	50	28 (56%)	22 (44%)	27 (54%)	7 (14%)	–
1989–1992	8	1 (13%)	7 (88%)	1 (13%)	1 (13%)	–
1986, 1987, and 1993–1996	42	27 (64%)	15 (36%)	26 (62%)	6 (14%)	–

[†] WWA was not evaluated in 1988, 1989, and 1992 because of water-stress symptoms and the low level of disease symptoms.

‡ H = significantly higher disease severity for a particular treatment, followed by number of analyses.

Table 3. Effect of tillage on leaf spot disease severity on spring wheat (SWA)[†] after sunflower, averaged across N and cultivar. The tillage effects summarized are the mean differences between the specified tillage in contrast to the other two tillage treatments.

Year	Total no. of ratings	Statistical differences		Tillage [‡]		
		Significance at $P < 0.05$	No significant difference	NT	MT	CT
1996	6	0	6	—	—	—
1995	9	7	2	H 7	—	H 3
1994	7	7	0	H 7	—	—
1993	2	1	1	—	H 1	H 1
1991	3	0	3	—	—	—
1990	2	0	2	—	—	—
1989	2	0	2	—	—	—
1987	10	6	4	—	H 6	H 5
1986	6	1	5	H 1	—	—
Overall	47	22 (47%)	25 (53%)	15 (32%)	7 (15%)	9 (19%)
1989–1992	7	0	7 (100%)	—	—	—
1986, 1987, and 1993–1996	40	22 (55%)	18 (45%)	15 (38%)	7 (18%)	9 (23%)

[†] SWA was not evaluated in 1988 because of water-stress symptoms and the low level of disease symptoms. Not all tillage treatments were evaluated in 1992 because of water-stress symptoms and the low level of disease symptoms.

[‡] CT = conventional till; H = significantly higher disease severity for particular treatment, followed by number of analyses; MT = minimum till; NT = no-till.

have a larger impact on disease severity than tillage or crop rotation.

Nitrogen fertilization influenced leaf spot disease severity in 56% of the 50 WWA evaluations (Table 2), 45% of 51 SWA ratings (Table 1), and only 10% of 61 SWF ratings (data not shown). When differences were evident among N treatments in the WWA and SWA evaluations (annual cropping system), higher levels of disease severity were usually associated with the low N treatment (Fig. 3 and 4). For the few times differences were evident among N treatments in the SWF evaluations, higher levels of disease severity were associated with the low N treatment. One can speculate that a low level of differences among the N treatments in the SWF evaluations was a result of the low N plots having near-adequate N (Halvorson et al., 2001b). This could be due to the available soil N resulting from mineralized N of organic matter that became available due to a longer fallow period in the spring wheat–fallow system compared with the shorter fallow period in the annual cropping system.

Higher N fertilization levels apparently had a positive effect in reducing disease severities under our environmental conditions. Anderson et al. (1998), reporting on this project, indicated that with annual cropping the weed community declined almost 60% at the high N rate (101 N kg ha⁻¹) compared with the low N rate (34 N kg ha⁻¹).

Table 4. Effect of cultivar treatment on leaf spot disease severity, averaged across tillage and N.

Crop [†]	Total no. of ratings	Statistical differences		Cultivar [‡]	
		Significance at $P < 0.05$	No significant difference	Stoa	Butte86
SWA	51	10 (20%)	41 (80%)	H 2 (4%)	H 8 (16%)
SWF	61	13 (21%)	48 (79%)	H 9 (15%)	H 4 (7%)
				Roughrider	Norstar
WWA	50	16 (32%)	34 (68%)	H 13 (26%)	H 3 (6%)
Overall	162	39 (24%)	123 (76%)		

[†] SWA = spring wheat in an annual cropping system, SWF = spring wheat in a spring wheat–fallow system, and WWA = winter wheat in an annual cropping system.

[‡] H = significantly higher disease severity for a particular treatment, followed by number of analyses.

DeVuyst and Halvorson (2004) also reported earlier that higher N rates generated the highest profits on this project. The decrease in disease severity with higher N treatments is consistent with a study on winter wheat in which disease severity was reduced with higher N applications when converting grassland to cropland (Krupinsky and Tanaka, 2001). In Saskatchewan, Fernandez et al. (1998b) observed an increase in leaf spot severity on spring wheat with an increase in N deficiency with dry summers. Tompkins et al. (1993), also in Saskatchewan, reported that greater Septoria/Stagonospora (*P. nodorum* and *M. graminicola*) development on winter wheat was associated with low N fertility in only one trial out of nine. They suggested that lesion development may be promoted by N deficiency or a nutrient imbalance. In addition, Huber et al. (1987), in Indiana, reported that the severity of tan spot on soft red winter wheat cultivars decreased as the N rate increased. In contrast, high rates of N fertilizer have been reported to increase the severity of septoria/stagonospora diseases on winter wheat in Pennsylvania (Broscious et al., 1985), Kentucky (Ditsch and Grove, 1991), and Tennessee (Howard et al., 1994). Apparently, increasing rates of N fertilizer may increase, decrease, or have no effect on

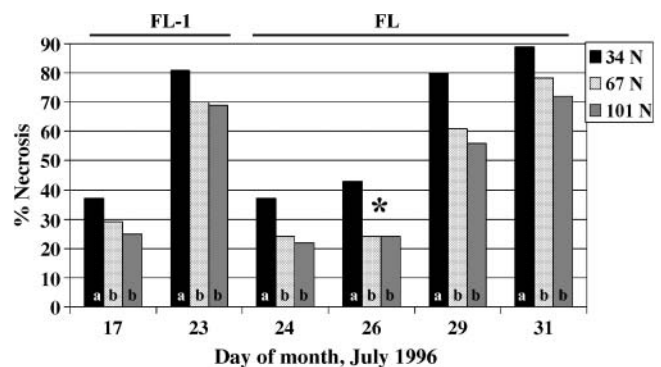


Fig. 3. Effect of N fertilization (kg N ha⁻¹) on leaf spot disease severity on spring wheat after sunflower, averaged across tillage and cultivar. Treatments with different letters for a particular date are significantly different ($P \leq 0.05$). Asterisk (*) indicates significant N \times tillage interaction; FL = flagleaf, uppermost leaf; FL-1 = first leaf below the flagleaf.

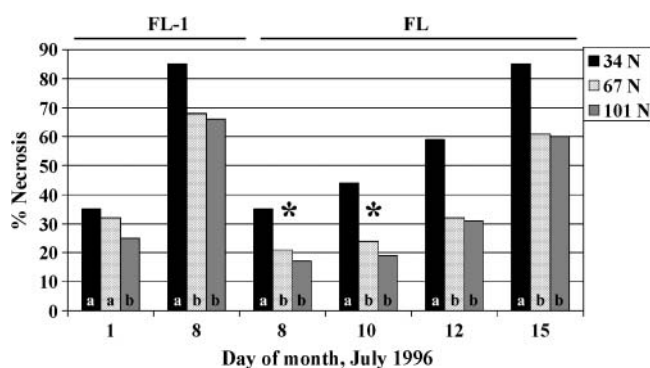


Fig. 4. Effect of N fertilization (kg ha^{-1}) on leaf spot disease severity on winter wheat after spring wheat, averaged across tillage and cultivar. Treatments with different letters for a particular date are significantly different ($P \leq 0.05$). Asterisk (*) indicates significant N \times tillage interaction; FL = flagleaf, uppermost leaf; FL-1 = first leaf below the flagleaf.

disease severity depending on the region or prevailing environment (Krupinsky, 1999).

When evaluating tillage treatments for the SWA crop, statistical differences among treatments for severity of leaf spot diseases occurred in 47% of 47 SWA evaluations during 11 yr (Table 3). Differences were most evident in 1987, 1994, and 1995, but not detected during five continuous years with low precipitation, 1988 to 1992. In 1987, near the beginning of the project, a higher level of disease severity was associated with the MT and CT treatments compared with the NT treatment. Because lower crop residue coverage of the soil, on which leaf spot pathogens carryover, was associated with the MT and CT treatments, this was unexpected. In 1994 and 1995, the NT treatment had higher levels of disease severity than the MT and CT treatments. One can speculate that there was a build up of inoculum on carryover residue from 1993 because of the favorable precipitation levels in 1993. Higher disease severity was associated with the NT treatment compared with the MT and CT treatments in mostly two of the 11 yr with the SWA evaluations (Table 3). Overall, when differences among treatments were significant, NT was associated with higher levels of disease severity in 15 evaluations (42% of 47 evaluations).

When evaluating tillage treatments for the SWF crop, differences in disease severities did not occur during five continuous years with low precipitation, 1988 to 1992. Differences among tillage treatments for disease severity occurred in only 16% of 61 SWF evaluations during 11 yr, indicating that leaf spot diseases on the SWF crop were usually not impacted by tillage treatments under our conditions. Statistical differences among tillage treatments were detected during 3 yr: one out of seven evaluations in 1994, one out of six in 1996, and seven out of nine in 1995. In 1995, high levels of disease severity were associated with the NT treatment compared with the MT and CT treatments for the SWF evaluations. One could speculate that because of the high precipitation in 1993, residue from the 1993 crop (fallowed in 1994) would have been a good source of inoculum for the 1995 crop. Overall, when differences among treat-

ments were significant, NT was associated with higher levels of disease severity in only nine evaluations (15% of 61 evaluations).

When evaluating the WWA crop, differences among tillage treatments for disease severity did not occur during five continuous years with low precipitation, 1988 to 1992. Differences among tillage treatments for disease severity occurred in only 20% of 50 WWA evaluations during 11 yr, indicating that leaf spot diseases on winter wheat were usually not impacted by tillage treatments under our conditions. Differences among tillage treatments were evident during five growing seasons: one out of eight evaluations in 1986, three out of 11 in 1987, one out of three in 1990, one out of five in 1991, and four out of seven in 1995, with most being detected during 1987 and 1995. In 1987, a higher level of disease severity was associated with the MT and CT treatments compared with the NT treatment, similar to the SWA evaluations. In 1995, the NT treatment had higher levels of disease severity than the MT and CT treatments, again similar to the SWA evaluations. Overall, when differences among treatments were significant, NT was associated with higher levels of disease severity in only seven evaluations (14% of 50 evaluations).

A tillage \times N treatment interaction was only significant for 12% of the WWA evaluations, 15% of the SWA evaluations, and 21% of the SWF evaluations. A significant tillage \times N treatment interaction usually indicated that the level of disease severity was higher for the NT treatment than the CT and MT treatments at the low N level, and the NT treatment was similar to the CT and MT treatments at higher N levels. For example, disease severity under NT was much higher at the low N level for both WWA and SWA evaluations when the interaction was significant (Fig. 5). Available soil N was usually lower under NT than MT and CT at all N rates (Halvorson et al., 1999b, 2001a). This indicates the importance of adequate N fertilization when using NT under our conditions.

Differences in disease severity among cultivar treatments occurred only 24% of time (Table 4). With the WWA evaluations, lower levels of disease severity were usually associated with the cultivar Norstar compared with Roughrider, when differences were detected. In another report, Norstar had lower leaf spot disease severity than Norwin, a semidwarf cultivar (Tompkins et al., 1993). When differences between the spring wheat cultivars were detected, the results appeared to be impacted by the cropping system. Higher disease severities were associated with Butte86 in the annual cropping system with 16% of the SWA evaluations (Table 4). In contrast, higher disease severities were associated with Stoa within the spring wheat-fallow system with 15% of the SWF evaluations. Thus, differences in disease severity between the spring wheat cultivars included in the project were not consistent.

CONCLUSIONS

In general, leaf spot diseases of wheat were influenced by tillage, N fertilization, and cultivars. The long-term

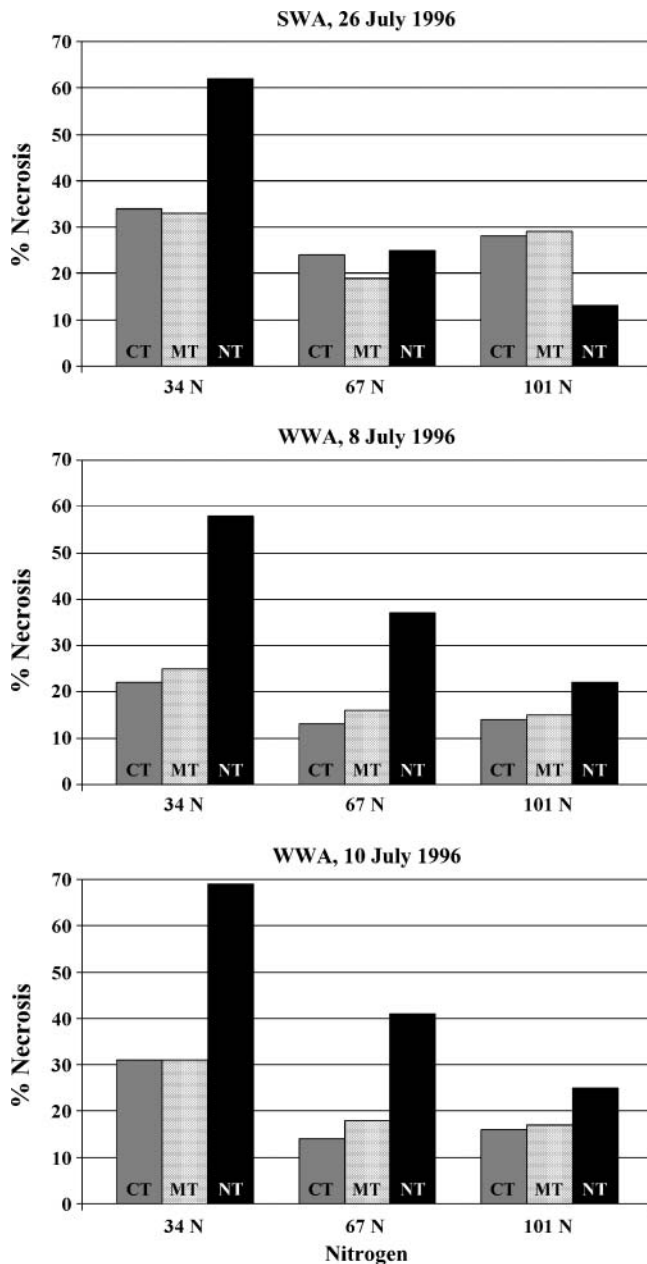


Fig. 5. Examples of significant N (kg ha⁻¹) × tillage interactions for leaf spot disease severity on spring wheat (SWA) after sunflower (Fig. 3) and winter wheat (WWA) after spring wheat (Fig. 4), averaged across cultivars. CT = conventional till, MT = minimum till, and NT = no-till.

nature of this project provides an insight on how differences among treatments can vary among years. During the drier years, the impacts of management practices on leaf spot disease severity were minimal. The use of NT did not consistently increase the severity of leaf spot diseases. Using NT during the drier years apparently has an advantage by conserving soil water when moisture is limiting without increasing the risk to leaf spot diseases. When N treatments influenced leaf spot diseases, higher levels of disease severity were associated with the low-N fertilizer treatment compared with higher levels of N fertilization, indicating an advantage of using adequate

N fertilizer especially with NT. The use of adequate fertilizer especially with NT appears to reduce the risk to leaf spot diseases under our environmental conditions. When differences in leaf spot diseases for cultivars were evident, Norstar winter wheat had lower levels of disease severity compared with Roughrider. Differences between the spring wheat cultivars appeared to be impacted by the cropping system, with higher disease severities associated with Butte86 in the SWA system and with Stoa in the spring wheat–fallow system. With newer cultivars available, producers should select the most resistant cultivars available for their cropping systems to lower the risk of leaf spot diseases. Producers should integrate a combination of practices to develop a consistent long-term strategy for disease management that is suited to their production system and location. Risks can be lowered with additional management practices of crop rotation/crop sequence, fungicide application, and control of weeds and volunteer crop plants (Krupinsky et al., 2002).

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